SECTION 9.0
PERMEABLE BARRIER ECONOMICS

The economical benefit of permeable barriers has been an important driving force behind the widespread interest in this technology. At chlorinated solvent-contaminated sites, where the plume could continuously be generated for several years or decades, a passive technology that requires almost no annual energy or labor input (other than for site monitoring) has obvious cost advantages over a conventional pump-and-treat system. A cost-benefit approach that includes both tangible and intangible costs and benefits should be used in evaluating the economic feasibility of a permeable barrier at a given site.

9.1 CAPITAL COST CONSIDERATIONS

The capital cost of installing a permeable barrier includes the following items:

- Cost of the reactive medium
- Cost of the emplacement
- Technology licensing costs
- Cost of disposal of spoils and restoration of ground surface.

The unit cost of the reactive medium depends on the type of medium selected. Granular iron is the cheapest of the available metallic media, and therefore has been the most commonly used. Only when special site requirements necessitate the use of a different medium may other more costly options be preferred. Although initial field applications are reported to have paid up to $650/ton for the granular iron, identification of additional sources has reduced the unit cost of iron available to approximately $350/ton (ETI, 1996).

The total cost of the reactive medium is driven not only by the unit cost of the reactive metal, but also by the amount of reactive metal required. The amount of reactive metal required depends on the following site-specific factors:

- **Type and Concentrations of the Chlorinated Contaminants.** Contaminants that have longer half-lives require a larger flowthrough thickness of the reactive cell, and therefore higher cost.

- **Regulatory Treatment Criteria.** The more stringent the treatment criteria that the barrier has to meet, the greater the residence time required; the greater the residence time, the greater the thickness of the reactive cell must be, thereby increasing the cost.

- **Groundwater Velocity.** The higher the groundwater velocity, the greater the thickness of the reactive cell required to obtain a certain residence time, and therefore the higher the cost.

- **Grondwater Flow and Contaminant Distribution.** At sites where the distribution of groundwater flow or contaminants is very heterogeneous, a reactive cell of uniform thickness and extent can lead to an inefficient use of reactive medium. Emplacement of the reactive cell in zones of higher permeability or the use of funnel-and-gate configurations and pea gravel-lined cells are some of the ways in which the use of a reactive medium may be made more homogeneous.

The unit costs of emplacement depend on the type of technique selected, which, in turn, depends on the depth of the installation. Table 7-1 (in Section 7) summarizes the emplacement techniques available, the maximum depth possible for each technique, and some representative unit costs obtained from several geotechnical contractors. Although some variability in the cost of each technique represents differences in vendors, the range of unit costs is more likely driven by depth. The total cost of emplacement is based on three main factors:

- **Plume and Aquifer Depth.** For a given emplacement technique, the upper part of the cost range generally applies to the greater depths in its range.

- **Plume Width. The** greater the width of the plume, the wider is the permeable barrier required to capture it.

- **Geotechnical Considerations.** The presence of rocks or highly consolidated sediments may make it harder to drive the emplacement equipment (e.g., sheet piles or caissons) into the ground.

Given the cost difference between the emplacement techniques for the funnel versus those for the reactive cell in Table 7-1 (Section 7), there may be a cost trade-off between selecting a funnel-and-gate system versus a continuous reactive barrier. Disposal of spoils generated during emplacement is another cost that may vary based on the emplacement technique selected. For example, slurry walls generate more spoils than does emplacement of sheet piles. Disposal of spoils could be costlier if the barrier has to be located within the plume, in which case the spoils may have to be disposed of as hazardous waste. Restoration of the site surface may include returning it to grade or repaving the surface for built-up sites.

For each permeable barrier application, ETI, which holds a patent for the zero-valent iron technology, charges a licensing fee of up to 15 percent of the capital costs (materials and construction costs) for the application of the technology. A limited warranty is provided by ETI guaranteeing degradation as long as the required residence time is achieved (ETI, 1996). Other patented media (e.g., Fe-Pd) may have similar licensing requirements. The University of Waterloo has a patent pending for the Waterloo Barrier technology of sheet piles with grout-sealed joints, although any licensing fees are included in the price of the technology.

9.2 OPERATING AND MAINTENANCE (O&M) COST CONSIDERATIONS

O&M costs for the permeable barrier include the following items:

- **Compliance Monitoring Costs.** These costs will vary from site to site depending on regulatory requirements, number of monitoring wells, and frequency of sampling.

- **Additional Performance Monitoring Costs.** If additional monitoring is desired to achieve other engineering objectives (see Section 8.2), these costs will vary depending on the objectives of each site.

- **Periodic Maintenance Costs.** Maintenance may be required if precipitates build up to a point where either the reactivity or the hydraulic conductivity of the reactive cell is significantly affected. The reactive cell may have to be flushed with reagents, or the reactive medium may have to be replaced. Indications from existing permeable barrier sites are that such maintenance would be infrequent at most sites.

There currently is no clear basis for estimating maintenance costs, mainly because their frequency of occurrence, if at all, is not known. Rule-of-thumb criteria that have been used for economic analysis at previous sites include a maintenance cost estimate that assumes 25 percent of the reactive metal will be replaced every 10 years for sites with low precipitation potential, and every 5 years for sites with high precipitation potential (ETI, 1996). Estimating the longevity of the permeable barrier and devising methods for rejuvenating or replacing it, if required, are some areas in which additional research efforts are required.

9.3 COST-BENEFIT EVALUATION

Table 2-2 (in Section 2) summarizes the capital costs of permeable barriers at various sites with different barrier configurations and emplacement techniques. All these sites used granular iron as the reactive medium. In evaluating the economic feasibility of a permeable barrier application, the estimated capital costs and projected operating costs of a permeable barrier may be compared to similar estimates for a pump-and-treat system or other remedial option.

Some sites have been using a 30-year time period over which to estimate costs of a permeable barriers project. The net present value (NPV) of the project is determined as follows:

$$NPV_{project} = \text{Capital costs} + NPV_{O\&M\ costs}$$

$NPV_{O\&M\ costs}$ = Sum of annual O&M costs adjusted for inflation and cost of capital over 30 years.

An $NPV_{project}$ can be calculated separately for a pump-and-treat system and for the permeable barrier option, and then compared to evaluate the projected lifetime costs of the two approaches. Sometimes the economic benefits of a permeable barrier may not be obvious. At one existing site (Warner et al., 1996), the site owner was able to lease the property after installing a permeable barrier only because there were no aboveground structures. Such benefits may be included as a cost-reducing element in the NPV. Other intangible benefits should also be considered in the economic analysis.

Any economic benefits of a permeable barrier application may be included in the analysis as an offset (or reduction) to capital or O&M costs. For example, if installation of a permeable barrier results in the sale of a property that was previously unsalable because of the need to operate aboveground pump-and-treat systems, then the sale value can be used to offset capital costs. If a permeable barrier installation results in the ability of the owner to lease or otherwise put a previously unused property to productive use, the NPV of the annual cash flows from the lease or other use may be used to offset the NPV of the O&M costs of the barrier. Intangible benefits, such as the risk reduction achieved by emplacing the barrier, should also be considered.

9.4 COMPUTERIZED COST MODELS

The Remedial Action Cost Engineering and Requirements (RACER) System is an environmental costing program developed by the U.S. Air Force. It can estimate costs for various phases of a remediation project:

- Site Characterization Studies (Underground Storage Tank [UST] Site Assessment, RI/FS, RCRA [RFI/CMS])

- Remedial Design
- Remedial Action (including Operations and Maintenance)
- Site Work and Utilities.

The program's framework is based on actual engineering solutions gathered from historical project information, construction management companies, government laboratories, vendors, and contractors. It is designed to factor in specific project conditions and requirements based on minimal user input to generate a cost estimate. RACER Version 3.2 has a cost database created mostly from the U.S. Army Corps of Engineers' Unit Price Book and supplemented by vendor and contractor quotes. Version 3.2 has been adapted specially for permeable barrier applications. It runs through a four-step process in creating a cost estimate (Delta Research Corp., 1996).

- **Establish an Active Project Site.** When you create an estimate, you must first establish an active project site by one of three methods: (1) add a new project site, (2) select an existing project site, or (3) copy an existing project site to a new project site.

- **Calculate Site (Direct) Cost.** A project may be comprised of a single site or it may contain several sites. For each site included in the project, select and run the technologies and/or processes (cost models) that will be used to remediate the site. The costs calculated for these models are direct costs only (i.e., the cost does not include contractor overhead and profit, cost for contingencies, project management, or escalation).

- **Calculate Project Costs.** Having run and calculated the direct costs for all cost models included in each site for the project, complete the estimate by calculating the project costs. Project costs include costs for contractor overhead and profit, contingencies, project management, and escalation. Because these costs apply to the entire project, they need to be calculated only once, unless the direct costs are changed.

- **Run and Print Reports.** Having completed the estimate, print the reports. You may print up to five different reports, with varying levels of detail. For example, you may print a report exclusively for the direct costs (Detail Cost Report), or you may print a report for the total project cost (Project Cost Report).

A flowchart showing a more detailed breakdown of the RACER 3.2 estimating process is shown in Figure 9-1.

As an option for estimating the total project cost for installing a permeable barrier system, RACER 3.2 is very detailed and includes direct costs for remedial action professional labor, sampling and analysis, remedial design, construction phases, and operation and maintenance. The estimate is calculated based on minimal input from the user. The required input includes the following:

- Site location
- Starting/completion dates for various phases of the project
- Projected hours for involved staff

The *RACER* Estimating Process

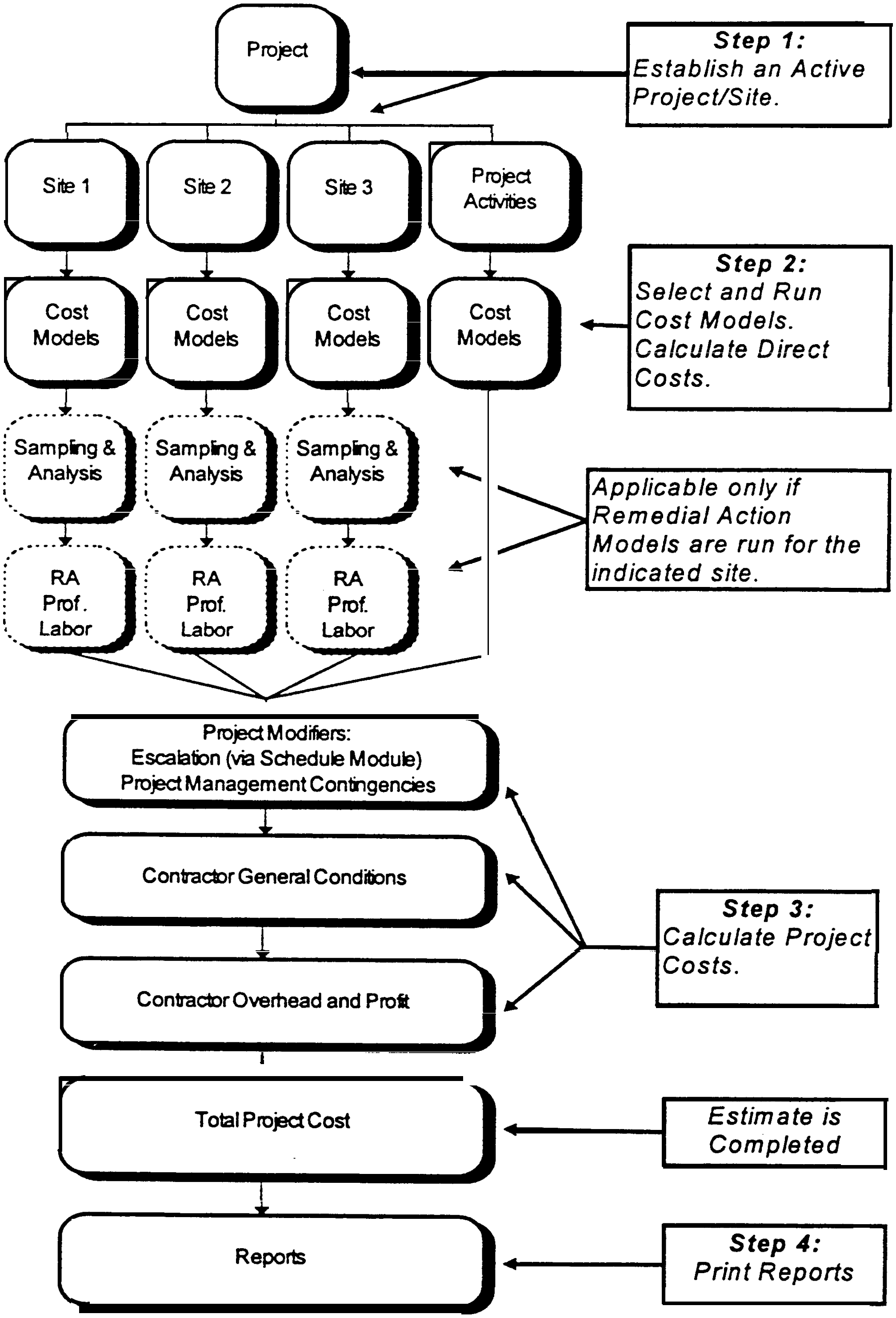

Figure 9-1. RACER Version 3.2 Process Flowchart (RACER, 1996)

- Type of barrier
- Dimensions and media used for funnel-and-gate walls.

Many default values have already been inserted and need to be carefully scrutinized. The user must be fully aware of all the different cost models available. Careful screening of the itemized cost breakdown within each individual cost model will enable the user to edit the estimate and customize it to fit his/her needs (e.g., deleting the cost for a chemical toilet if one is already provided on site).

Some major limitations to the RACER model include the following:

- Restriction to only three design types

  1. Continuous reactive barrier
  2. Funnel-and-gate system with sheet piling (for funnel walls)
  3. Funnel-and-gate system with slurry wall (for funnel wall).

- No options for innovative emplacement techniques, such as jetted barriers, sealable-joint sheet piles, geomembranes, composite walls, caissons, etc.

- Limited methods of excavation. The model assumes all trenches up to 25 feet are excavated by a backhoe, and trenches 26 to 120 feet are excavated under a slurry. It does not mention devices such as clamshells or continuous trenchers.